Methodology to quantify the effect of policies and measures in emission reductions from road transport

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Abstract

Atmospheric emissions from road transport have increased all around the world since 1990 more rapidly than from other pollution sources. Moreover, they contribute in more than 25% to total emissions, in the majority of European countries. This situation confirms the importance of road transport when complying with emission ceilings (e.g. Kyoto Protocol and National Emissions Ceilings Directive).

The developed methodology illustrates the effect on transport emissions of the most influential variables and their relationships. Therefore, it would be a policy instrument to design emission reduction measures.

Firstly, the influence of the main variables was studied: mileage or mobility (passengers or tonnes) per vehicle type (cars, buses, light duty vehicles, heavy duty vehicles, mopeds, and motorcycles); fuel used (diesel, petrol, biofuels, natural gas, and LPG); driving mode (urban, rural, and highway) and vehicle speed; technology used (Euro types, hybrid vehicles, and electric vehicles by power); vehicle characteristics (power, load factor, age, operational life, etc.).

The second step consisted of defining several scenarios, changing the variables in order to analyze both the individual and combined effect of these on emissions (sensitivity analysis). These scenarios evaluate the effect of changes in the previous factors, according to realistic policies and measures (e.g. penetration of Euro 5 and 6, increase of biofuel use, scrapping systems, etc.)

The third step included the development of an holistic model to estimate emissions which allows the quantification of the effect of both technical and non technical measures. The model is called EmiTRANS and it estimates the emissions in a flexible and coherent way. It contributes to incorporate scientific data on decision making process.

Finally, this methodology has been successfully proven for the calculation of emission projections from road transport in Spain, up to 2020 under several scenarios.

Keywords: Road transport, emissions, methodology, Policies and Measures

1 Introduction

Road transport is a major source of air pollutant emissions in world cities (Gurjar *et al* [1], Colvile *et al*). Moreover, vehicle exhaust emissions have been the cause of much concern regarding the effects of urban air pollution on human health (Curtis *et al* [3]).Subsequently, local authorities have the need to develop strategies to control vehicular emissions through technological and socioeconomical measures. For this reason, an effective assessment of possible future measures to reduce air pollution is required for future traffic planning, regulatory and fiscal initiatives.

As an example, Spanish CO_2 emissions from road transport have increased in an 80% during the period 1990-2005, which constitutes a higher percentage than the increase in the number of vehicles for the same period (fig. 1). The opposite situation occurs with SO_2, since reductions in S content of fuels have dropped the emissions in a 97% for the same period. CO and VOC emissions have declined a 56%. NOx emissions were stabilized while $PM_{2.5}$ and have only increased a 24%. However, when the emission trend is below the mileage trend, it means that engines have been improved, since they have evolved to emit less amount of pollutant for the same distance travelled.

In the last few years, and intended to reduce emissions from road transport in a cost-effective way, some important efforts have been made worldwide to study the effect of the implementation of policies and measures on emissions. For instance, Seika *et al*. [4] estimated changes in the concentration of NOx and other pollutants from vehicle emissions under different traffic control strategies; Sælensminde [5] presented cost-benefit analyses of walking and cycling, planning to reduce the effect of motorized transport; Shrestha *et al*. [6] determined cost effective passenger transport technology and energy options to reduce nitrogen oxides emission from the transport sector in Beijing, China during the period 2005–2020 and also for Beijing.

However, as authors are aware, up to date it does not exist a consistent methodology to evaluate emission reductions in road transport from both technical and non-technical measures. This paper presents a methodology and includes the development of a tailored software tool. Pollutants considered are those related to typical air quality problems in urban areas (SO_2, NOx, NMVOC, heavy metals, CO and particulate matter) and CO_2 and N_2O as greenhouse effect gases.

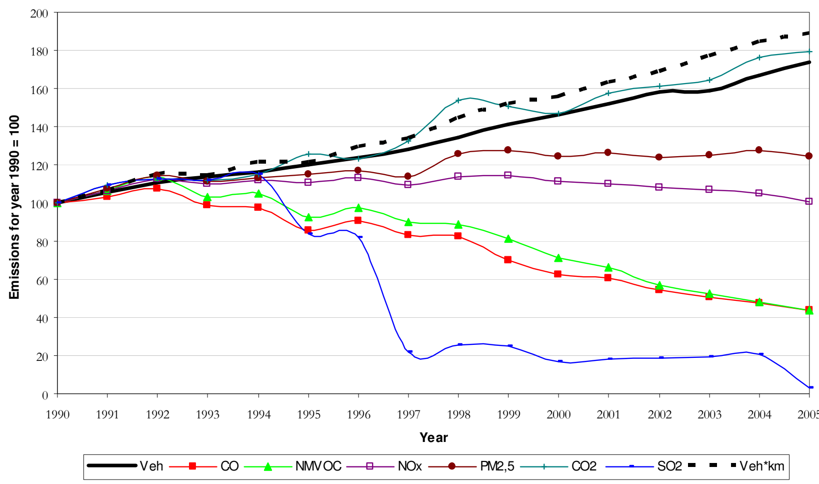

Figure 1. Historic trend of Spanish road transport emissions vs. mileage and number of vehicles

2 Methodology

First of all, we have analysed the factors that have an influence on emissions from road transport. We have selected the main parameters that generate emissions from road vehicles from the methodology, most of which are included in the EMEP/CORINAIR methodology [7]. They are shown in table 1 including their metric.

Secondly, we have developed a software tool called EmiTRANS which allows the inclusion of the technical and non-technical measures leaded to quantify their influence in emissions reduction. In turn, it consists of three parts as shown in fig. 2. The first one corresponds to the inputs which are divided into two types: i) factors that are highly influenced by P&M and ii) factors that do not depend on P&M because they are related to climatic issues or need structural or long-term changes to evolve.

This tool is designed with two purposes: to obtain results on the calculation of emissions (outputs) through Copert4 software (Gkatzoflias *et al.* [8]) and to obtain other outputs that are useful to get conclusions.

Finally, we have applied EmiTRANS to the case of Spain (a country included in the European Union). This application consists of three steps, as indicated in fig. 3. The first step comprises the inclusion of input data. These are divided into six different sectors: passenger cars, light duty vehicles, buses, heavy duty vehicles, mopeds, and motorcycles. For each sector, information on fuel consumption, technologies, driving mode, average speed, etc. according to classification from table 1 is required. To allow the maximum flexibility to the process, some of the inputs are optional. That is, it is not necessary to introduce information for all the variables as the programme can calculate variables using other information. For instance, if no data are available on future number of vehicles per technology type, they are calculated through life vehicle curves and estimations of penetration of new technologies in the future.

Table 1: Selection of factors that influence in the emissions

Scope	Factors determining emissions	Units
Passengers & Freight	Passenger mobility	passenger·km
	Freight mobility	tonnes·km
	Occupancy rate for passenger vehicles	passengers/vehicle
	Load factor for freight vehicles	Tonnes/vehicle
Fuel use	Fuel distribution by vehicle type	% of petrol, diesel, LPG, Natural Gas, Hydrogen.
	Fuel consumption by vehicle type	l/100 km
Driving modes	% mileage by driving mode	% mileage for urban, rural and highway mode
	Average speed	Km/h
	Efficient driving	Reduction in fuel consumption
	Frequency of private transport use	% of mobility by private vehicle
	Average mileage per vehicle	km/year
	Distance driven in urban environment	km/year
Vehicles	Vehicle distribution by ages	% vehicles by registration year
	Vehicle distribution by engine cylinder capacity and maximum weight	%
	Life vehicle curves	%
	Factor for mileage reduction for vehicle ageing	%
	Average load for freight vehicles	Tonnes/vehicle
Techno-logies	New technologies distribution for the vehicle sales by year	% of technology-i from total sales by year
Climatic factors	Maximum temperatures	ºC
	Minimum temperatures	ºC

In the second step, implicit variables (those that are not directly used in EMEP/CORINAIR methodology, e.g. mileage in units of passenger·km, occupancy rate, load factor, etc.) are transformed into explicit variables (e.g. mileage in veh·km). Afterwards, Quality Assurance /Quality Control (QA/QC) procedures are used (e.g. check that the sum of % is equal to 100, contrast if parameters are in a previously assigned range, etc.). Eventually, developed algorithms are applied to obtain outputs.

As an example of these algorithms, fig 4 shows the way that disaggregation of new vehicles by technology is obtained. On one hand, the number of vehicles by sector for the reference year that will be driven in the future is obtained using life vehicle curves, reduction of mileage due to vehicle ageing, and vehicle registration dates of existing technologies. On the other hand, the total number of projected vehicles for future years (reference years and future years) is obtained using forecasted mobility in passenger·km and freight·km and through application of occupancy rates, load factors, expected average distance driven by vehicle type, etc. Finally, number of new vehicles is calculated subtracting vehicles from previous technologies to total future vehicles.

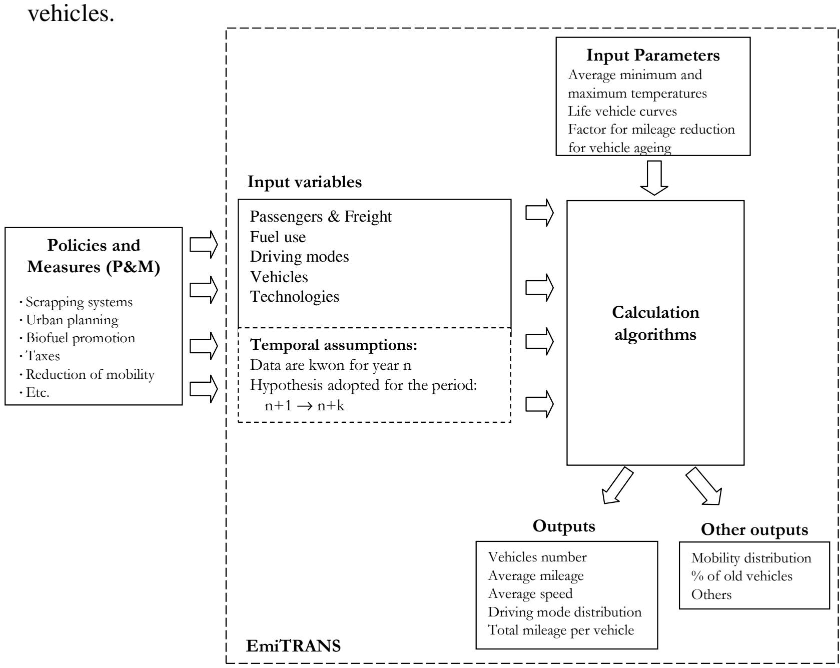

Figure 2. EmiTRANS design

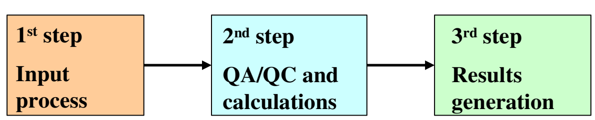

Figure 3. Steps for running EmiTRANS

In the last step (3rd step), results are generated according to Copert4 requirements. These outputs are, for instance, the number of vehicles for each year by sector, subsector and technology; average speed by type of vehicle;

sector and driving mode; fuel characteristics (Reid Vapor Pressure, Sulphur content, etc.); fuel consumption by subsector, etc. Other outputs are also obtained in order to have more info at one's disposal. These tables are, for instance, the number of vehicles and mobility by sector, subsector and technology

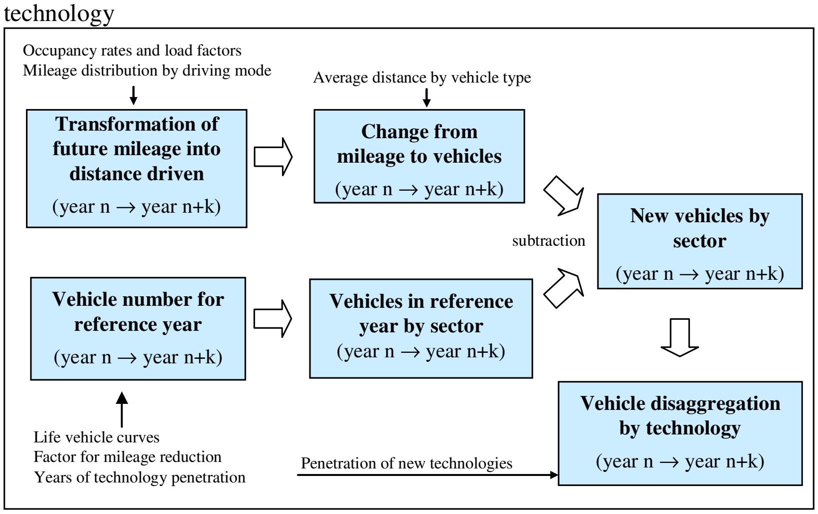

Figure 4. Disaggregation of new vehicles by technology

3 Application to Spain

The method has been successfully applied to Spain, carrying out a sensitivity analysis of the factors mentioned in section 2 and using the EmiTRANS tool to develop five scenarios of Spanish road transport emissions up to 2020.

The sensitivity analysis has been done according to the changes included in table 2 to identify the influence of several factors in atmospheric emissions. Fig 5 and 6 represent the results for several cases. Fig. 5 shows that to reduce CO and NMVOC is more effective to apply scrapping systems for 20% of old cars (renewing them with the most updated engines) than reducing mobility by 10%. Nevertheless, measures aimed to decrease the mobility by 10% are more incisive to reduce CO_2 and $PM_{2.5}$. In fact, CO_2 emissions remain almost constant when scrapping measures are applied. This is due to the fact that newer technologies have decreased fuel consumption but not as effectively as air pollutants. For NOx emissions, both kinds of measures have the same effect. Concerning the analysis of the joint effect, the figure demonstrates that the effects of measures are not accumulative since the sum of the individual effects is higher than the joint effect.

Fig. 6 evidences that P&M intended to reduce mobility are more productive declining every type of pollutant. Their effect is higher for CO, NMVOC, NOx, $PM_{2.5}$ and CO_2. Furthermore, in this case the joint analysis leads to even higher reductions than the sum of individual effects. This aspect provides evidence that the joint application of measures would result in a larger reduction due to synergic effects.

Table 2: Selection of factors that influence on the emissions

Factor	Sensitivity analyses
Fuel distribution for vehicles	Reference: 46.6% petrol, 53,4% diesel
	30% petrol, 70% diesel
	40% petrol, 60% diesel
	60% petrol, 40% diesel
	70% petrol, 30% diesel
Urban average speed	Reference: 25 km/h
	20 km/h
	22.5 km/h
	27.5 km/h
	30 km/h
Highway average speed	Reference: 105 km/h
	84 km/h
	94.5 km/h
	115.5 km/h
	126 km/h
% of large vehicles	Reference: vehicles with engine cylinder>2 l are 6.2% for petrol and 14.2% for diesel
	Number of large vehicles are tripled
	Number of large vehicles are doubled
	Number of large vehicles are divided by 2
	There is no large vehicle
Number of old passenger cars	Reference: 5,375 M vehicles (26.5 %)
	20% substitution by Euro 5 vehicles
	40% substitution by Euro 5 vehicles
	60% substitution by Euro 5 vehicles
	80% substitution by Euro 5 vehicles

Regarding emission projections, the main assumptions for each of the five scenarios are shown in table 3. These assumptions were used to calculate emission projections using the methodology and EmiTRANS model as presented in section 2.

As an example, fig. 7 displays the results for CO_2 emissions. The larger emissions correspond to the BAU (Business As Usual) scenario. It does not include any technological measure and the passenger and freight mobilities evolve as they did in the past (from 1990-2005). The lowest scenario is the "lower mobility". This remarks that the most effective measure to reduce CO_2 emissions is the mobility cutback. The other scenarios project similar emissions: baseline has the higher emissions but not far away from the promotion of biofuels and higher technology penetration. That is, in 2020 emissions from baseline scenario are 25% higher than in 2005 while the increase are of 14 and 18% for "technological" and "Biofuel promotion" scenarios respectively.

Table 3: Selection of factors that influence in the emissions

Scenario	Mobility	Technology in 2020	Power	Biofuels
Business as usual	+4% PC +6% HDV	Same as baseline	Same as baseline	Same as baseline
Baseline	+3.6-0.5% PC +5.1-0.2% HDV	1.4% Electric/H_2 3.2% Hybrid 16% NG urban buses	Petrol: 41%<1,4l; 52%∈1,4l-2l; 7%>2l Diesel: 86%<2l; 14% >2l	2010: 5.83% 2012: 8% 2016-2020: 10%
Technological	Same as baseline	10% Electric/H_2 20% Hybrid 50% NG urb. buses	Same as baseline	Same as baseline
Lower mobility	No mobility increase	Same as baseline	Same as baseline	Same as baseline
Biofuel promotion	Same as baseline	Same as baseline	Same as baseline	2010: 6.88% 2012: 9.5% 2020: 20%

PC: Passenger Cars. HDV: Heavy Duty Vehicles.

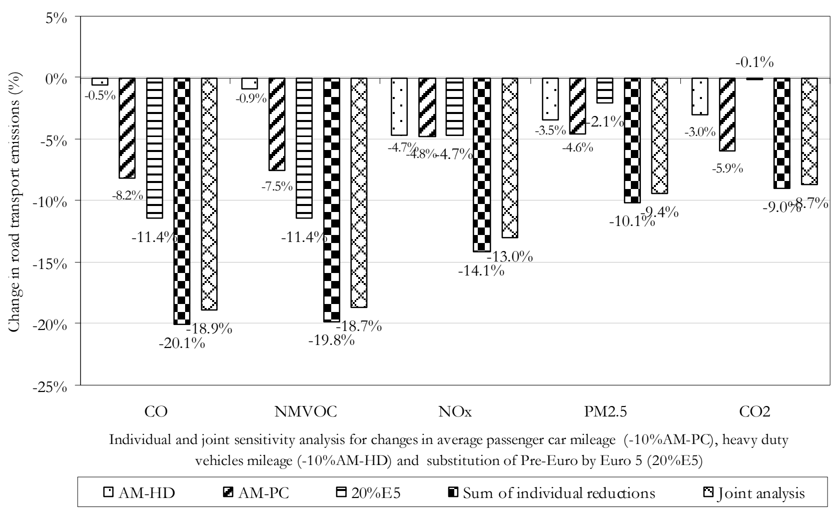

Figure 5. Sensitivity analysis for changes in average mileage and technology penetration

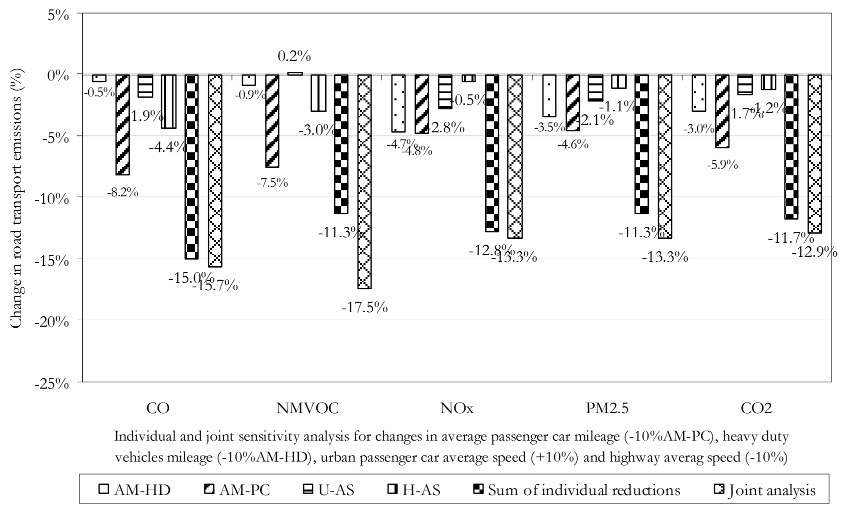

Figure 6. Sensitivity analysis for changes in average mileage and average speed

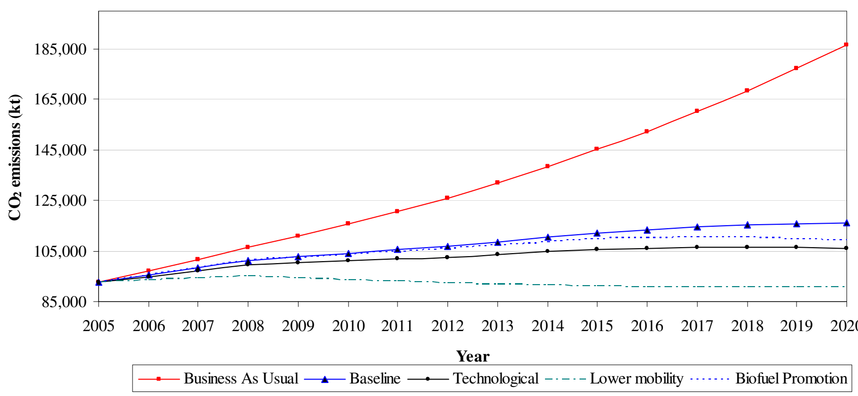

Figure 7. Spanish CO_2 emission projections for road transport

4 Conclusions

We have developed a methodology to quantify the effect of policies and measures on emission reductions from road transport. It includes the analysis of past emission trends and the development of a model called EmiTRANS which is able to estimate the influence of several factors over emissions in a flexible and coherent way. It contributes to incorporate scientific data on decision making process.

This methodology has successfully been applied to the case of Spain. It shows the importance of some variables in road transport emissions. According to the sensitivity analyses done, the most influent variables for CO, NMVOC, NOx and $PM_{2.5}$ emissions are passenger car mileage, and scrapping systems for vehicle substitution. The reduction of passenger car mileage allows a reduction on total road transport emissions of 8.2%, 7.5%, 4.8%, and 4.6% respectively, while old vehicle substitution by Euro 5 reduces emissions by 11.4%, 11.4%, 4.7% and 2.1%. However, to obtain CO_2 reductions, non-technical measures such as increasing average speed in cities and decreasing it in highways, are more effective than scrapping systems. They produce a decline of a 1.7% and a 1.2% in road transport emission respectively while scrapping systems only reduce CO_2 emissions by 0.1%.

This methodology also allows the development of different emission scenarios for future years. The application to Spain for the period 2006-2020 under several scenarios, shows that for instance, the most effective measures to abate CO_2 emissions are those aimed to reduce passenger and freight mobility.

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